



*Two Sensors
for Distributed Satellite Platforms*

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TWO SENSORS FOR DISTRIBUTED SATELLITE PLATFORMS

by

Gregory H. Canavan

ABSTRACT

Sensors are well suited to deployment on highly-proliferated satellite platforms like singlet space-based interceptors (SBIs). Proliferated radars could achieve useful search rates. The simplest could be little more than altimeters that looked directly below to provide a continuous fence against low-flying aircraft. Mounting them on the SBI lifejackets should be inexpensive. Bus watching is a rough alternative to discrimination. Proliferation could allow multiple sensors to observe buses above the horizon at close ranges.

I. INTRODUCTION

This note discusses two sensors well suited to deployment on highly proliferated satellite platforms of the type that could be available if the 5,000-10,000 satellites necessary for single-interceptor SBIs are deployed. If they are, the satellites could be as little as a few hundred kilometers apart over the northern part of their coverage,¹ which would make possible observations from several sensor platforms at short ranges. This note discusses sensors for aircraft detection and bus watching that could be so deployed effectively.

II. AIRCRAFT DETECTION

Detection schemes based on infrared sensors are limited by low signals and weather. Radar satellites are all-weather, but it is difficult to produce beams narrow enough to give adequate search rates against cluttered backgrounds.² Proliferated platforms make even narrow fields of view useful.

A. Sensor

The simplest sensor could be a radio ranger or altimeter that looked below the satellite. If the altimeter was at altitude h , it would receive a return from the ground after a time $2h/c$, where c is the speed of light. An object at altitude z would give a return in $2(h-z)/c$. Over oceans, northern wastes, or poles the terrain is relatively flat, so the return would be relatively uncluttered. That would result from the vertical geometry, not any sophistication in the transmitter, which could be essentially omnidirectional. In looking down, the satellite could detect any targets higher than the vertical extent of the terrain clutter. For large radars viewing at oblique angles, keeping clutter to manageable levels would cost careful beam forming and extensive signal processing.

B. Search

The altimeter could look out to some angle from the vertical. The signal from a target at altitude z and range r from the vertical from the satellite would return to the satellite before that from the ground directly below the satellite if

$$r < \sqrt{(2hz)}. \quad (1)$$

For an aircraft ingressing over the pole at $z \approx 10$ km, the maximum radius is $r \approx \sqrt{(2 \cdot 500 \text{ km} \cdot 10 \text{ km})} \approx 100$ km, for a near-term platform altitude of ≈ 500 km.³ Thus, the satellites could look out to $\approx \tan^{-1}(r/h) \approx 10^\circ$, which would give them a search rate of $\approx 2 \cdot 500 \text{ km} \cdot 8 \text{ km/s} \approx 8,000 \text{ km}^2/\text{s}$. That is modest compared with the $\approx 5 \cdot 10^8 \text{ km}^2$ of the surface of the earth or even with the $\approx 10^8 \text{ km}^2$ of the northern approaches, but if there are $\approx 10^4$

satellites in the constellation, their combined rate could cover the latter in $\approx 10^8 \text{ km}^2 \div 10^4 \cdot 8,000 \text{ km}^2/\text{s} \approx 1 \text{ s}$. With a satellite every 100 km that can look out to $\approx 100 \text{ km}$, the constellation would provide essentially complete, continuous coverage.

Their coverage would drop for lower-altitude aircraft, but only quadratically in altitude. From Eq. (1), for aircraft at 1 km the satellites could look out to $\approx 30 \text{ km}$; for 100 m out to $r \approx 10 \text{ km}$. Continuous coverage would be lost, but the satellites move at 8 km/s and the aircraft at $\approx 0.2 \text{ km/s}$, so in the $10 \text{ km} \div 0.2 \text{ km/s} \approx 50 \text{ s}$ it would take a very low-altitude aircraft to cross the satellites' track, the satellites would move $\approx 8 \text{ km/s} \cdot 50 \text{ s} \approx 400 \text{ km}$. That means a number of satellites would cross overhead as the aircraft crossed their search zone. Thus, the satellites would still provide a continuous fence against even very low-flying aircraft.

Viewed from above, aircraft should have large signals, which could be difficult to reduce. Active means could act as a beacon to the other satellites in sight viewing in bistatic geometries. Data on those signals could be gathered in peacetime as part of the satellites' normal altitude-measuring function.

C. Track

Hits from a number of successive satellites could probably be assembled into good enough tracks to commit air-to-air or ground-to-air missile or fighters, but the signals actually have more detailed information. Even for nondirectional transmitters and receivers, the satellites could get precise track information on a target from the variation of its time delay as the satellite passed over it. If the motion of the aircraft is ignored, the delay from a target a distance x to the side of the satellite's track would vary as

$$D(t) = 2\sqrt{[(h-z)^2 + x^2 + (Vt)^2]}/c, \quad (2)$$

for $x^2 + (Vt)^2 < 2hz$ from Eq. (1), where V is the satellite's velocity and t is time, measured from the point of closest approach. By observing the variation of $D(t)$ knowing h , ignoring

$z \ll h$, and estimating the point of closest approach, the satellite could estimate

$$\langle x \rangle \approx \sqrt{[(CD(0)/2)^2 - h^2]}. \quad (3)$$

Since about 20-50 s of signal would be available on each overflight, and the main errors due to scintillation only, the point of closest approach could be estimated accurately. The residual error could be in the measurement of $D(0)$, which could be reduced by shortening the pulse. Doppler information could be included in the process with only a modest modification of the receiver. The estimate of Eq. (3) is ambiguous as to whether the aircraft is north or south of the satellite, which could be resolved by using track information from successive contacts, moving the feed, or using two feeds and varying their phase.

D. Transmitter

The receiver would look down at the $T \approx 300^\circ \text{K}$ earth, which should be the dominant noise, but the aircraft's cross sections should be measured in m^2 , so the average power transmitted should be small. Crudely, if E (Joule) is transmitted in a pulse of duration τ , the peak power in the return signal is

$$S \approx [E/\tau(4\pi h^2)][\sigma/(4\pi h^2)]A, \quad (4)$$

where $\sigma \approx 10 \text{ m}^2$ is the aircraft's scattering cross section, and $A \approx 1 \text{ m}^2$ is the receiver's area.⁴ The background noise power is $\approx BkT$, where $k = 1.4 \cdot 10^{-23} \text{ J/degree}$ is Boltzmann's constant and $B \approx c/2z \approx 3 \cdot 10^8 \text{ m/s} \div 2 \cdot 10 \text{ km} \approx 1.5 \cdot 10^4 \text{ Hz}$ is the full receiver bandwidth. Thus, the signal-to-noise ratio is

$$S/N \approx E\sigma A/\tau(4\pi h^2)^2 BkT, \quad (5)$$

so that for $S/N \approx 10$ and $\tau = 0.1 \mu\text{s}$, detection requires an energy

$$\begin{aligned} E &\approx (4\pi h^2)^2 \tau BkT(S/N)/\sigma A \\ &\approx [4\pi(10^5 \text{ m})^2]^2 0.1 \mu\text{s} \cdot 1.5 \cdot 10^4 \text{ Hz} \cdot 1.4 \cdot 10^{-23} \text{ J/}^\circ \cdot 300^\circ \cdot 10/10 \text{ m}^4 \\ &\approx 0.1 \text{ Joule}. \end{aligned} \quad (6)$$

The satellite crosses a search zone in $10\text{-}100 \text{ km}/10 \text{ km/s} \approx 1\text{-}10 \text{ s}$, so one pulse per zone would take $\approx 0.1\text{-}1 \text{ Watt}$ average power. The pulses could probably be broken up into $10\text{-}100$ pulses $1\text{-}10\%$ as large for finer resolution.

E. Deployment

A fundamental simplification results from the fact that the whole altimeter could be mounted on the "life jacket" or support system for the SBI rather than on the SBI itself. Mass added to the former can be deployed for essentially the cost of launch; mass added to the latter has an additional ≈ 30 -fold penalty because it is accelerated with the SBI kill package. The lifejacket should have adequate power and, arguably, room for the ≈ 30 -cm antenna required.

F. Assessment

The assembly could weigh less than a kilogram. The significance of the mission would justify its separate deployment, but the availability of numerous SBI platforms with just the power, capacity, communication, and orbits needed would make the altimeters natural add-ons. In proliferated deployments the altimeters would avoid the clutter, power, and beamwidth problems that have driven space radars to large monoliths and made them forever a research project for the next decade. The radars' deployment against bombers, cruise missiles, and cruise missile carriers would remove one of the fundamental objections to phase 1 strategic defense deployments: that airbreathing threats would underfly the defenses and destroy all they depended on or sought to defend. The proliferated defenses would do so for a cost that can be estimated from the relative masses of the altimeter and SBI kill package to be a 10-20% increase in the SBI hardware costs.

III. BUS WATCHING

Decoys are the greatest weakness of near-term strategic defense deployments.⁵ The best way of dealing with them would be through solid discrimination.⁶ Failing that, the next best is narrowing the number of objects to a level at which all can be intercepted.⁷ Still one more step removed is watching their release in hopes of identifying their time of release in a threat

cloud precisely enough that only a portion of it needs to be sanitized in midcourse.

A. Conventional Satellites

Conceptually appealing, bus watching from conventional satellites is technically and financially demanding. Geosynchronous boost-phase warning satellites cannot see bus burns at all. Even large lower satellites are driven to such low constellation sizes that they must view the bus from $\approx 3,000$ km, from where with a 30-cm telescope, at $3 \mu\text{m}$ wavelength their resolution is $\approx 3,000 \text{ km} \cdot 3 \mu\text{m} / 30 \text{ cm} \approx 30 \text{ m}$, which is much larger than the bus. These problems in signal, geometry, and resolution have undercut passive observation and discrimination.⁸

B. Distributed Deployments

Deploying simple tracking telescopes on the SBIs' life jackets could overcome all three problems. It allows them to observe the buses above the horizon against cold space, to view from in close and from favorable angles, and to achieve much higher resolution with modest apertures. Current active buses could produce only a few tens of Watt/sr in the infrared. If, however, the telescopes only viewed them above the horizon, that is more than enough to track and convert that track to gates on the bus itself, which in useful long-wavelength infrared bands should have a signal of $\approx 10 \text{ W/sr}$.

The lifejacket would have modest intelligence, but not much would be required to take a track handover from its pebble before launch, or in a short message once the order of battle was sorted out. Or the sensor could simply reacquire the bus, since above the horizon there would be little background. The telescope could be shielded from earth- and sunshine before launch. It would not need to be cooled; signal should be adequate; and noise would not be a problem. Deployment would have to wait till until the smoke cleared from the pebble's departure, but it would have 200-300 s before the missiles and buses reached their 300-400 km altitude.

C. Ranges

Each telescope could take the closest bus with a good viewing geometry and watch it. There should be plenty of life jackets. For a near-term launch, about 5,000 SBIs would be needed, so about 1,000 lifejackets should be over or just outside the launch area. If 30% of the buses leaked through the SBIs,⁹ there would be ≈ 3 telescopes per bus.

Over the launch areas the life jackets would be $\approx 4 \cdot R_e / \sqrt{(zN)} \approx 4 \cdot 6,400 \text{ km} / \sqrt{(4 \cdot 4,000)} \approx 200 \text{ km}$ apart. The typical passing range would be $\approx 70 \text{ km}$; the bulk of bussing would be done at ranges under 200 km. Thus, even a 10-cm telescope would be able to resolve $\approx 100 \text{ km} \cdot 10 \text{ } \mu\text{m} / 0.1 \text{ m} \approx 10 \text{ m}$, and a 30-cm telescope could resolve $\approx 3 \text{ m}$, enough to distinguish the bus and put tracking gates on it. That would enable its motion to be observed very precisely. The objective would not necessarily be to image the bus, only to register it from frame to frame so real accelerations of the bus during offloading could be determined.

D. Telescope

Thus, the detector array for the telescope could be little more than a quad detector. It would need to be cooled, but only for a few minutes, and there would be adequate time for blowdown during deployment of the telescope. The telescope would literally be a tracking scope, not one of the current large imaging cameras. The information on the bus's motion could essentially be read off encoders on the telescope's gimbals as it moved to track the bus with a loop closed around its own detectors. The lifejacket has enough stabilization to provide an adequate platform and enough memory and communications to transmit the measurements of the bus's motions out to midcourse--perhaps through the local pebble communication bucket brigade.

E. Metrics

Midway through deployment the bus would weigh ≈ 6 tonnes, so dropping a 300-kg reentry vehicle would alter its mass $\approx 5\%$ and

its acceleration a like amount for constant thrust. If the reentry vehicle was dropped at a thrust of 0.2 g, that would give a change of acceleration of 0.01 g, or 0.1 m/s^2 , which from 100 km would give a $1 \text{ } \mu\text{rad/s}^2$ signal, which should be readily measurable with simple telescope. If the bus dropped its thrust to mask the mass loss, from this range it should be possible to detect that from the change in luminosity of its exhaust. Only a few percent accuracy is required.

Knowing the time of release of the reentry vehicle and the trajectory of its accompanying threat cloud narrows its position within its cloud of decoys just enough that only those around the suspected object need be killed. If the number of decoys can be narrowed down to about 10 per RV, ground-based interceptors can kill them all effectively without further discrimination.

F. Assessment

The technical keys are that the densely proliferated life jackets give several telescopes a good, close look at each bus's deployment, and that the power, stabilization, and communication are already present on the life jackets. The mission would again justify their deployment, but platform costs tend to drive those deployments in the direction of few, large, distant complex imaging telescopes that simply are not affordable with today's costs and yields. The SBIs' paying the overhead makes cheap, proliferated platforms available, and the kilogram masses involved do not reduce the SBIs' survivability. They might increase it since the attacker would have to kill them too to try to prevent the transmission of this valuable information.

IV. OBSERVATIONS

This note has discussed two sensors suited to deployment on highly proliferated satellite platforms of the type that would be available if single-defender SBIs are deployed. They could make it possible to observe buses or airbreathing threats with several sensors from multiple platforms at short ranges.

Radar satellites are all-weather, but with large platforms it is difficult to produce beams narrow enough to give adequate search rates against cluttered backgrounds. Proliferated sensors can achieve useful search rates even with narrow fields of view. The simplest sensors could be little more than altimeters that looked below the satellites. Their returns would be relatively uncluttered for useful search areas, even for simple transmitters. They would provide a continuous fence against even very low-flying aircraft, getting precise track information on targets from the variation of time delays as the satellites passed over it. The transmitter requirements are modest.

A fundamental simplification results from the altimeter's being mounted on the life jacket rather than on the SBI itself. The availability of numerous platforms with the power, capacity, communication, and orbits needed at little incremental cost would make the altimeters natural add-ons. They would avoid the clutter, power, and beamwidth problems that have driven space radars to large monoliths and kept them in research.

The deployment of proliferated sensors against bombers, cruise missiles, and carriers would remove the fundamental objection to phase 1 strategic defenses: that air-breathing threats would underfly them and destroy all they relied on or sought to defend. They could do so at the cost of a 10-20% increase in the SBI hardware costs.

Watching buses to identify the time of release of their RVs is a rough alternative to good discrimination, but signal, geometry, and resolution problems have undercut passive observation. Proliferated deployment could allow multiple sensors to observe the buses above the horizon against cold space, to view close in from favorable angles, and to achieve much higher resolution with modest telescopes. Signals should be adequate; noise should not be a problem.

Required SBI constellations could provide several telescopes per bus. Typical observation ranges would be ≈ 100 -200 km. Thus, the detector arrays for the telescope could be little more than quad detectors. Information on bus motion could be read off

encoders on the telescope's gimbals as it tracked the bus. Life jackets should have enough stabilization to provide an adequate platform and enough memory and communications to transmit measurements of bus motions out to midcourse. The changes of acceleration should be readily measurable with simple telescopes and mounts.

The key to each deployment is that the densely proliferated SBI life jackets give good geometries for radar ranging, that they offer several telescopes a close look at each bus's deployment, and that the power, stabilization, and communication needed are already largely present on the life jackets. The SBIs' paying the overhead would thus make cheap, proliferated platforms available without compromising their survivability.

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